T 37/58

[redacted]

[redacted]

Copy No. 33
44 Pages.

SC
12R4

[redacted]

UK UNCLASSIFIED 18/9/84 Y.McA

[redacted]

[redacted] [redacted]

ES5/~~[redacted]~~/241

DECLASSIFIED FOR PRO
BY AWE ALDERMASTON.

UNITED KINGDOM ATOMIC ENERGY AUTHORITY

ATOMIC WEAPONS RESEARCH ESTABLISHMENT

REPORT No. T 37/58

OPERATION ANTLER

(32)

Target Response Group
(Group Leader Plans: E. R. Drake Seager)
(Group Leader Operations: Lt.Col. E. T. Wray, REME)

The Shielding from Initial Radiation Afforded by Soil

Maj. D. B. B. Janisch, RA

[redacted]

[redacted]

[redacted]

[redacted]

A.W.R.E.,
Aldermaston, Berks.

November, 1958

[redacted]

[redacted]

United Kingdom Atomic Energy Authority

ATOMIC WEAPONS RESEARCH ESTABLISHMENT

REPORT NO. T37/58

OPERATION ANTLER

Target Response Group

(Group Leader, Plans; E. R. Drake Seager)
(Group Leader, Operations; Lt. Col. E. T. Wray, REME)

The Shielding from Initial Radiation Afforded by Soil

Maj. D. B. B. Janisch, R.A.

Summary

During both Round 2 and Round 3, measurements of γ-radiation doses and neutron fluxes were made at depths below the surface of the ground varying from 1 ft to 6 ft. Protection factors have been calculated. The experiments have shown that serious errors are likely to occur when measuring the γ-radiation dose from certain types of weapon with a quartz fibre or other ionization chamber type of dosimeter.

[redacted]

Table of Contents

Table of Contents (Cont.)

[redacted]

1. Introduction

On Operations Hurricane, Totem and Buffalo, trials were carried out to measure the protection from initial radiation afforded by various fieldworks and AFVs. The most recent of these trials (Operation Buffalo) is reported in Ref. [1].

After Operation Totem, Major L. Cave, RAOC, who had carried out some shielding trials, made recommendations for future trials (which are included as an Appendix to Ref. [1]). Some of the recommended trials were included in the plan for Operation Buffalo.

When analysing the results obtained at Operation Buffalo, it became clear that it was desirable to obtain more information about the shielding capabilities of earth in circumstances where confusion of the results by scattered radiation could not occur. After Operation Totem, one suggestion was to sink a small diameter pipe into the earth, and to place therein dosimeters at different depths. While making the initial preparations for the Antler trial, it was thought desirable to measure neutron fluxes as well as the γ-dose at different depths, because it had been shown in Ref. [1] that in some circumstances, the neutron hazard in a shielded position is as great as, or even greater than the γ-hazard. To accommodate neutron dosimeters, it was necessary to use a pipe of wider diameter than had originally been suggested; this necessitated a change in the method of the trial, which is described in detail in Section 3.2 below.

The protection afforded by the earth against neutrons, and against γ-radiation, has been treated separately in the remainder of the report.

As in previous reports, the Protection Factor (PF) has been defined as:-

$$PF = \frac{\text{Free air dose or flux at site}}{\text{Dose measured at particular point in shielded position}}.$$

2. Objects of the Trial

The objects of the trial were firstly to determine the protection factors afforded at various depths in soil, against γ-radiation and thermal and fast neutrons, and secondly to investigate any variation of these protection factors with distance from point of burst, weapon design or height of burst.

3. Method

3.1 Types of Dosimeter Used

3.1.1 γ-Dosimeters

It was decided to use three types of γ-dosimeter:-

(a) Service Phosphate Glass.

(b) AWRE Film/Phosphor.

(c) Service (or Service Type) Quartz-Fibre. Three varieties of these were used:-

- (i) Type QF(A) The Prototype Dosimeter No. 5 used at Operation Buffalo.
- (ii) Type QF(B) The Service Dosimeter No. 5.

(iii) Type QF(C) QF(B) with the ionisation chamber partially evacuated to 1/3 atmospheres and with the capacitance adjusted accordingly.

The differences between these three types of quartz-fibre dosimeter, and the reasons for their use are discussed in detail in Section 4.2 below.

3.1.2 Neutron Dosimeters

The standard AWRE method of neutron dosimetry [1] is to expose samples of pure elements in a steel tube 18 in. long, 2 in. external diameter and about $\frac{1}{4}$ in. wall thickness. The elements become radioactive on irradiation and it is possible to measure fast (greater than 3 MeV) neutrons using sulphur*, total slow neutrons using unclad gold† and epithermal neutrons using gold clad with cadmium. The thermal neutrons may then be obtained from the latter two results by subtraction.

For the present trial a modified form of the AWRE standard tube was used. This was 6 in. long, 2 in. external diameter and about $\frac{1}{4}$ in. wall thickness and contained three discs, one of gold, one of gold wrapped in cadmium and one of sulphur. A tube, with its contents, is shown in Figure 1.

3.2 Positioning of Dosimeters

The original suggestion was to sink a 2 in. diameter pipe into the ground; the angle subtended at the mouth of the pipe by any distance-piece separating dosimeters would then have been sufficiently small for its density to be unimportant. In this trial, however, it was necessary to accommodate the neutron dosimeters as well, and as it was essential that all three elements in these dosimeters should be at

---

* $^{32}S\ (n,p)\ ^{32}P$. (Half-Life = 14.3 days).

† $^{197}Au\ (n,\gamma)\ ^{198}Au$. (Half-Life = 2.69 days).

the same depth, a wider tube was necessary. Finally, it was decided to have 7 in. diameter holes made in the ground by a well-boring machine which was available. It was not desirable to employ the alternative method of blowing a crater and back-filling since this would introduce unknown variations in the density of the earth surrounding the shield.

A series of holes were bored to a depth of not less than 6 ft, at varying ranges from the Ground Zero of Rounds 2 and 3. Twin holes were dug at each site - the holes being separated by a distance of 3 ft, on a line at right angles to the radius from Ground Zero. For various administrative reasons, it was not found possible to sink twin holes for Round 2, and there were five single holes at ranges from 1350 to 2850 ft approximately from Ground Zero. For Round 3, twin holes were sunk at six sites from 1650 to 3500 ft slant range from the expected point of burst.

The holes were lined with thin steel tube to prevent caving in. To maintain the density of the shield within the tube, and at the same time facilitate the recovery of the dosimeters, the latter were placed at pre-determined positions in cylindrical cans of thin sheet steel which were subsequently filled with soil. These cans were slightly less in diameter than the bore of the holes, and had loops so that they could be lowered into the holes by a "shepherd's crook". The positions of the dosimeters were such that, when the cans were lowered into the holes, they were at the correct distances below the surface. A cross-section of a typical hole is given in Figure 2, and photographs of the cans, sunken pipes, etc. are given in Figures 3 - 6.

3.3 Distribution of γ-Dosimeters

The depths at which particular types of dosimeters were used were decided from the doses which were predicted from theoretical considerations and experience at Operation Buffalo. Thus phosphate glass and quartz-fibre dosimeters were not placed where the predicted dose was less than 10 r. The quartz-fibre dosimeters would not have been used anywhere where the dose was expected to exceed 1000 r, had

it been possible to predict the received dose accurately, but because of uncertainties regarding the yield and design of the weapons actually fired, quartz-fibre dosimeters were placed alongside the phosphate glass dosimeters throughout. There was always an overlap between the higher reading dosimeters (phosphate glass and quartz-fibre) and the film/phosphor dosimeters. Very few type QF(C) dosimeters were available, and these were placed at positions where doses of between 300 r and 500 r were expected. Unfortunately in several cases the predictions were not sufficiently accurate to ensure that the dose actually received lay within this range. A summary of the distribution of the γ-dosimeters is given in Table 1.

TABLE 1

Distribution of γ-Dosimeters

Type of Dosimeter	No. of Dosimeters at Each Depth	
	Round 2	Round 3
Phosphate glass	2	2 × 2 = 4
Film/Phosphor	1 pack	2 × 1 = 2 packs
QF(A)	2	2 × 2 = 4
QF(B)	2	2 × 2 = 4
QF(C)	1 at selected depths only	1 at selected depths only

NOTE: The numbers of dosimeters in Round 3 were doubled in most cases, a complete set being placed in both of the holes at each range.

3.4 Distribution of Neutron Dosimeters

(a) Round 2

One tube (containing one sulphur disc, one clad gold disc and one unclad gold disc) was placed at each 12 in. position down each hole, i.e., at 12 in., 24 in. ....72 in.

(b) Round 3

One tube was placed at each 12 in. position down one of the twin holes at each position.

3.5 Protection from "Loose" Contamination

To prevent contamination of the dosimeters by soil rendered radioactive by the neutron flux, all the dosimeters were wrapped in polythene bags before placing into the cans. To prevent sand from being blown down the small gap between the cans and the tube during the time between "loading" the tubes and firing, and also to prevent sand and small stones being forced into the gap by the blast, a grommet of adhesive tape was wrapped round the top of each of the uppermost cans, which were then forced into position, making a virtually dust-proof seal.

3.6 Collection of Dosimeters

Recovery of the dosimeters was made as soon as possible after burst; the average time was about two hours. The recovery parties withdrew the cans with the "crooks" and placed them, as they were, into a Landrover trailer. As soon as all the cans were recovered, the parties withdrew to an area where the dose-rate was reasonably low, and the cans were then emptied out, and the dosimeters, still in their polythene wrappings, placed in containers. The latter were then taken to an area near Health Control where the dosimeters were unwrapped. As they were uncontaminated, it was possible to take them to the Village Laboratory area where they were read or measured.

3.7 Collation of Results

(a) γ-Dosimeters

The QF dosimeters were read in the normal way, and the results recorded. Certain correction factors had to be applied; this was done after return to the U.K.

The phosphate glass dosimeters were read on a reader in the usual manner, and the results recorded for information; as however there was some doubt about the calibration of the reader, the dosimeters were brought back to the U.K. where they were read on a standard reader in the Electronics Division of AERE where the dosimeter had been developed. The film/phosphor dosimeters were handed over to the RM Group at Maralinga, who processed the films and supplied the results to the author.

(b) Neutron Dosimeters

The elements from the neutron dosimeters were, as was mentioned above, activated by the neutron flux. In order to evaluate the flux, it was necessary to measure the amount of β-activity induced in the elements concerned. Measurements of β-activity were made on a standard Geiger-Müller counter and scaling unit - a 2 in. diameter type 2B2 end-window counter was used in association with a "Scaling Unit AERE Type 1221C" and associated power supplies. Counts were made of the dosimeter samples at intervals until decay curves which were plotted showed that the half-life was correct for the isotope whose measurements were required. These counts were then normalised to a standard shelf in the lead castle and extrapolated back to the time of burst. The position of the G-M tube relative to the standard shelf in the castle was calibrated by the use of a standard thallium source lent by the RM Group. This had been employed by them for calibrating the counting equipment which they were using for a similar purpose with their neutron dosimeters, the results of which would be used for the free-air flux/distance curves.

Some of the gold samples from Round 3 were so active that it was not possible to measure them on the equipment mentioned above until several half-lives had expired. In

some cases, this would have caused an untoward delay in leaving the range, so these samples were measured approximately at Maralinga, and then returned to the U.K. by air with the minimum of delay; on arrival in the U.K., the samples were taken to the Rutherford Laboratory of the Royal Military College of Science at Shrivenham, where measurements continued until the criterion given above had been met. A standard thallium source was also returned with these samples, so that it was possible to perform an accurate cross-calibration between the two sets of equipment, and to normalise the Shrivenham results to the same norm as was used for the Maralinga results.

The half-life of the phosphorus (^{32}P), measured in the sulphur samples from Round 3, is so long that measurement at Maralinga would have caused unnecessary delay. These samples were treated in the same manner as the gold ones mentioned above.

The normalised counts per unit time obtained were converted to neutron fluxes by using conversion factors which had been evaluated by the RM Group for converting their own results. The same factors were therefore used throughout by the RM Group and the author, thus preventing any errors in the protection factors which were calculated therefrom.

4. Results

4.1 γ-Dosimetry Results

Details of the γ-doses which were measured, and of the protection factors, are given in Appendix A. The Protection Factors are also shown graphically in Figures 7(a), 7(b), 10(a) and 10(b).

4.2 Reliability of Results

4.2.1 Quartz-Fibre Dosimeter

Certain types of quartz-fibre dosimeter are liable to read low when measuring large doses of γ-radiation delivered over a very short period of time [1], [2], [3]. To give the reasons for the decisions which are made below, it is necessary to give a brief resume of the situation regarding Service QF dosimeters over the period covering Operations Buffalo and Antler.

Originally, quartz-fibre dosimeters intended for measuring initial radiation (as opposed to residual radiation), were designed on the assumption that the substantial portion of the dose would be delivered at a dose-rate not exceeding 100 r/sec. As a result of experience on Operation Buffalo, it was decided that the Service dosimeter QF No. 5 should be calibrated so as to read full-scale doses accurately when delivered at dose-rates up to 600 r/sec [4]. This was possible for two reasons, firstly that the Service design (type QF(B) in this report) had improved geometry compared with the prototype (QF(A)), and secondly, that the scale had been adjusted so that at dose-rates not exceeding 600 r/sec, the dosimeter would read within ± 20% as opposed to + 0% – 40% as with the type QF(A).

On examination of the present results, it was found that discrepancies of up to a factor of more than 2 existed between the phosphate glass dosimeter results and those of the quartz-fibre (QF(B)) dosimeters. Even greater discrepancies were found in the case of the QF(A) dosimeters. These variations were discussed with members of the RM Group, and with the members of the Electronics Division of AERE who are concerned with the development of these dosimeters (Messrs. W. Abson, D. Peirson and F. B. Whiting). As a result of these discussions, three solutions seemed possible:-

(a) A greater sensitivity to neutrons in the case of the phosphate glass dosimeters.

(b) An inferior response by the quartz-fibre dosimeters due to the γ-radiation of energies greater than 2 MeV received from the radiative capture of neutrons in the atmosphere, **together with** the fact that any γ-radiation stemming from the neutron flux will be delivered at a high dose-rate.

(c) Increased errors in the quartz-fibre dosimeters because a substantial portion of the total dose may be delivered at a dose-rate considerably in excess of 600 r/sec.

These different possibilities of errors arising are discussed below:-

(a) Neutron Sensitivity

Phosphate glass and quartz-fibre dosimeters have been irradiated under similar conditions in a thermal reactor, and it was found that, for thermal neutrons, the sensitivity of the two types was similar and that a neutron flux of 10^{10} thermal neutrons/cm^2 enhanced the reading of either type of dosimeter by about 1 r. At the time of writing this report (February, 1958), little information was available on the relative sensitivity to neutrons with energies greater than thermal, but there is an indication that the response of both types of dosimeter to these energy neutrons is similar [6].

(b) Variations in Energy of Incident γ-Radiation

Differences in the surface densities of the two types of dosimeter will tend to make the quartz-fibre dosimeters read slightly low when measuring radiation with energies greater than the 2 MeV associated with the initial radiation from the cloud itself. In Ref. [7] it is shown that for the radiative capture of neutrons in the atmosphere (of which the reaction $^{14}N\ (n,\gamma)\ ^{15}N$ is one of the more important), a large proportion of the γ-photons have energies of greater than 5 MeV and some are of energies exceeding 10 MeV. In the same reference, it is suggested that, for low neutron-escape weapons, the contribution to the total γ-dose from the neutron capture reaction does not exceed 20%. It is reasonable therefore to assume that for Antler Rounds 2 and 3, where the neutron-escape was larger, the contribution of the higher energy (radiative capture) γ-rays to the total γ-dose was probably more than 50%.

Three individual errors can therefore be introduced by this:-

(i) The direct error due to the varying response of the instrument to γ-photons of different energies.

(ii) The fact that there will be greater attenuation of the lower energy (cloud) γ-radiation by the earth, so that in the deeper positions in the holes, the high energy (radiative capture) γ-rays will constitute a greater proportion of the total dose.

(iii) The time over which the two components of the γ-dose is delivered. This is discussed in more general terms below.

(c) Errors from High Dose-Rate

This seems to be the most probable source of error. The RM Group records show that in Antler Rounds 2 and 3, at 6000 ft from Ground Zero, approximately 35% of the total dose was delivered in 0.01 sec, and 76% in 0.3 sec* [5]. Application of these figures to a total dose of the order of 500 r. (the full-scale deflection on the dosimeter QF No. 5), shows that a large proportion of the dose must have been delivered at dose-rates considerably in excess of 600 r/sec. There is little practical confirmation that this will explain the very low relative readings of the quartz-fibre dosimeters compared with the phosphate glass, as it is not possible to simulate such high dose-rates in the laboratory with any degree of accuracy. However, it is reasonable to assume that the phosphate glass dosimeter should show less errors from high dose-rates (as it is the collection of dislodged **electrons** which is concerned in the measurement), than would the quartz-fibre dosimeter where comparatively heavy **ions** have to be collected. There is some additional confirmation from the partially evacuated quartz-fibre dosimeters (type QF(C)), which show smaller errors than the others.

---

* The data given here of the proportion of the dose delivered over different periods of time include the increased dose-rate due to the γ-rays from the radiative capture of neutrons in the atmosphere.

4.2.2 Other Dosimeters

It will be noted that, in some cases, there are discrepancies between the phosphate glass and the film/phosphor dosimeter readings. There is insufficient evidence to show which is correct, and for this reason, protection factors calculated for these results have been shown as a range.

It has been decided to use the phosphate glass dosimeter results in preference to any others when calculating protection factors, for the reasons given above, and also from information from Operation Buffalo. In Ref. [3], it is shown that in general, the phosphate glass dosimeter readings show better agreement with other methods of dosimetry than do the quartz-fibre.

The phosphate glass dosimeter readings which have been used have been adjusted to allow for the contribution to the recorded dose made by the neutron sensitivity of the dosimeter.

4.3 Neutron Dosimetry Results

Details of the neutron fluxes which were measured, and of the protection factors, are given in Appendix B and the protection factors are illustrated in Figures 8(a), to 9(b) and 11(a) to 12(b).

As was mentioned in Section 3.1.2, the thermal neutron flux is calculated by subtracting from the total slow neutron flux (measured by the unclad gold) the flux of epithermal neutrons (measured by the gold wrapped in cadmium). The results given in the Appendix have been treated in this manner, and fluxes of thermal neutrons and of fast (greater than 3 MeV) neutrons only have been given. It must be remembered that there will be in the neutron spectrum at any range from the point of burst, neutrons of energies above the thermal region and less than 3 MeV which have not been

detected and measured in this trial. The necessity of measuring these intermediate neutrons was discussed in Ref. [1], but at the time of preparing for Operation Antler, there was no really reliable method of measuring them readily available.

5. Discussion

5.1 γ-Dosimetry

(a) Round 2

From the results of the γ-radiation measurements made on Round 2 (an approximately 5 kiloton weapon burst on a 100 ft tower), it will be seen that the protection factors which were obtained in hole BI2 (1800 ft) are exceptionally high and are generally quite different from those obtained at similar depths at other positions. There is also a probably spurious low factor at 60 in. at position BI3 (2100 ft), and as this factor is determined by only one set of dosimeter results, too much reliance should not be placed on it.

In Appendix A to Ref. [1], it was suggested that for planning purposes, the following protection factors (Table 2) should be used for a ground (or low tower) burst. Mean factors obtained at Antler Round 2 are given for comparison.

TABLE 2

Predicted and Measured Protection Factors: Round 2

Depth, in.	6	12	24	36	48	60
Predicted P.F.	5	30	250	2000	2×10^4	2×10^5
Mean P.F. Obtained	2	5	30	300	2000	5000

Individual factors will of course vary appreciably from the "mean P.F. obtained" quoted above, but these latter figures are considered to be reasonably representative.

(b) Round 3

In the case of Round 3, (a balloon-burst at about 1000 ft of a 25 kiloton weapon) there were, unfortunately, some serious discrepancies between readings obtained by phosphate glass and film/phosphor dosimeters at 48 in. depth at positions TA4, TA5 and TA6. The results which are available are compared with those predicted in Ref. [1] in Table 3 below.

TABLE 3

Predicted and Measured Protection Factors: Round 3

Depth, in.	6	12	24	36	48	60
Predicted P.F.	1.7	10	80	400	4000	4×10^4
Mean P.F. Obtained	1.3	3	15	85	1000	$3\frac{1}{2} \times 10^3$ to $2\frac{1}{2} \times 10^4$

It will be seen that in the case of both rounds, the protection factors obtained were appreciably lower than those which were suggested. (It must be emphasised that the author of those suggestions said at the time that accurate prediction was very difficult.)

The manner in which the well-boring machine deposited the spoil on the surface made it impossible to analyse the material being bored out; Figure 4 shows typical spoil. One possible explanation of the higher protection factors measured at position BI2 would be that the hole was bored into sand instead of limestone; there was however no sign of this in the spoil. It would of course be possible for the area of the hole to be surrounded by a pocket of higher density sand although the hole itself was bored in limestone - this is considered unlikely.

5.2 Neutron Dosimetry

In Round 3 the exceptionally low protection factors afforded against thermal neutrons by 12 in. of soil are noteworthy. This is presumably due to the fact that the top foot of soil in situations like Maralinga contains few of the elements which are good absorbers of thermal neutrons.

There are variations in the factors for thermal neutrons at greater depths, but generally speaking, the variations are not excessive.

The protection factors for fast neutrons are more consistent.

6. Conclusions

This series of experiments has produced some more data on the shielding properties of the soil and subsoil from γ and neutron radiation, but the results obtained are still too variable from position to position to be of much value when designing field-works and other shelters. The uncertainty is accentuated when the varying designs of weapon are taken into account, as variations in the relative neutron escape will (a) change the γ-spectrum, and hence the γ-radiation protection factor, and (b) alter the relative hazard of the γ-rays and the neutron flux to persons within the shelter*.

These results confirm the conclusions arrived at in Ref. [1], namely that the protection factors predicted from data relating to low neutron-escape weapons are not valid for weapons of other design.

---

* The question of the relative neutron hazard was discussed in Ref. [1] and will not be repeated in this report, except to summarize the suggestions given therein on the relative biological hazards from acute doses of γ and neutron radiation. These suggestions were:

  3×10^9 thermal neutrons cm^{-2} or 3×10^7 fast neutrons cm^{-2} are equivalent biologically to 1 r of external whole body γ-radiation for short periods of irradiation, i.e., acute doses.

With high neutron-escape weapons, the rate of delivery of the γ-dose would appear to be so fast that instruments which are based on ionisation chambers, such as quartz-fibre dosimeters, are unable to collect all the ions produced in the chamber, and hence are liable to read low to an extent which makes it doubtful whether the reading has any real meaning.

The conclusion reached in Ref. [1] on group dosimetry again appears to hold. In that reference, it was suggested that the determination of the dose received by an individual from that measured by a "group dosimeter" was likely to be very misleading unless the exact position of the individual in the shelter was known.

A method of measuring neutrons of intermediate energies in experiments such as these is still required. There is no information at present of the hazard which would have resulted, in the circumstances of this trial, from the neutrons with energies of more than thermal but less than 3 MeV.

7. Recommendations

Further information is still required on the shielding from nuclear radiations afforded by the various forms of materials which could be used in the field. This applies particularly to shielding from neutrons, which is much more difficult to predict than that from γ-radiation.

A possible method of determining the shielding properties would be to use containers holding a known volume of the potential shielding material, of which the analysis, water content and density should be accurately known. Thin metal containers similar to an ordinary domestic dustbin should be suitable, with the dosimeters inserted into the centre of the mass of material. In this way, it would be possible to import samples of other soils and subsoils. This is considered particularly important from the point of view of neutron shielding, where small changes in analysis or water content can have appreciable effects. Although not strictly relevant to this report, it should be

noted that if this proposal was adopted, it would be possible to carry out a parallel series of experiments on the degree of neutron-induced activity produced in samples of soil from different parts of the world. This information is not readily available at present, and there is a tendency to regard all neutron induced activity in soils as being almost entirely from sodium.*

Consideration should be given to the suitability of quartz-fibre dosimeters for measuring initial γ-radiation under operational conditions, in view of the poor response to radiation received at a high dose-rate. For trials purposes, it is recommended that the use of these dosimeters, in their present form, should cease.

A method of measuring neutrons of intermediate energies, suitable for use in shielding experiments, should be developed, so that the hazard from these neutrons can be investigated.

---

* It would be possible to predict this activity, using the methods reported in Ref. [8] provided that the chemical analysis of the soil was very accurately known.

References

1. Maj. D. B. B. Janisch, et al.: "Operation Buffalo - The Shielding from Initial Radiation Afforded by Fieldworks and AFV's". AWRE Report No. T3/57.

2. Maj. D. B. B. Janisch et al.: "Operation Buffalo - Field Trials of Radiac Instruments in a Radioactively Contaminated Area" AWRE Report No. T2/57.

3. D. H. Peirson: "Operation Buffalo - Measurements with Phosphate Glass and Quartz-Fibre Dosimeters in the Field". AWRE Report No. T26/57.

4. G. C. Dale: Private communication on Operation Buffalo - January, 1957.

5. G. C. Dale: Private communication on Operation Antler - February, 1958.

6. D. H. Peirson and F. B. Whiting: Private communication - February, 1958.

7. R. A. Siddons: "Gamma Emission Resulting from the Radiative Capture of Neutrons by Nitrogen During an Atomic Explosion". AWRE Report No. E5/54.

8. Maj. D. B. B. Janisch: "Operation Antler - Neutron Induced Activity. AWRE Report No. T35/58.

APPENDIX A

γ-Radiation Measurements and Protection Factors: Round 2

Position and Ground Range, ft	Depth, in.	Phosphate Glass Dosimeters			Quartz-Fibre Dosimeters			Film-Phosphor Dosimeters	Accepted γ-Dose	External γ-Dose	Protection Factor
		Reading	Correction	Corrected Reading	(A)	(B)	(C)				
BI1	6	> 9000	N. A.	> 9000	O. S.	O. S.	-	-	> 9000	25610	< 2.8
(1348)	12	5025	336	4690	O. S.	O. S.	O. S.	-	4690		5.7
	24	600	34	565	200	340	O. S.	-	565		45
	36	55	0	55	35	35	-	-	55		470
	48	-	-	-	-	-	-	> 10	> 10		< 2500
	60	-	-	-	-	-	-	5	5		5100
	72	-	-	-	-	-	-	N. R.	-		-
BI2	6	1800	120•	1680	370	500+	-	-	1680	9940	5.9
(1800)	12	600	37	565	210	300	510	-	565		17
	24	55	2	55	40	60	60	-	60		170
	36	18	0	20	12	15	-	5.4	-		> 500
											>1800
	48	-	-	-	-	-	-	2.0	2		5000
	60	-	-	-	-	-	-	2.5	2		5000
	72	-	-	-	-	-	-	N. R.	-		-
BI3	6	1900	100•	1800	475	O. S.	-	-	1800	4000	2.2
(2100)	12	925	67	860	225	395	O. S.	-	860		4.6
	24	220	9	210	85	120	-	> 10	210		19
	36	20	0	20	25	25	-	0.75	20		200
	48	-	-	-	-	-	-	N. R.	-		-
	60	-	-	-	-	-	-	3.3	3		1300
	72	-	-	-	-	-	-	N. R.	-		-
BI4	6	950	40•	910	400	O. S.	-	-	910	2000	2.2
(2400)	12	375	15	360	150	250	-	-	360		5.5
	24	50	1	50	30	45	-	> 8	50		40
	36	10	0	10	10	15	-	5	10		200
	48	-	-	-	-	-	-	1.2	1		2000
	60	-	-	-	-	-	-	N. R.	-		-
	72	-	-	-	-	-	-	0.34	0.3		6600
BI5	6	360	30	330	190	275	300	> 10	330	800	2.4
(2850)	18	55	2	55	35	65	-	> 10	60		13.3
	30	10	0	10	10	20	-	4.5	-		> 80
											< 180
	42	-	-	-	-	-	-	1.3	1.3		600
	54	-	-	-	-	-	-	0.23	0.25		3200
	66	-	-	-	-	-	-	0.08	0.08		10^4

NOTES: O. S. = Off Scale. N. A. = Not applicable.

N. R. = Not recovered or No record.

• = Phosphate glass dosimeter correction from interpolated neutron data.

500+ = Fibre on QF dosimeter still visible.

All readings are in roentgen - final readings are rounded off.

The figures given are the mean of all the dosimeters of a particular type at that position. Any results which differ from the apparent mean by more than the specification limits (± 20%) have been rejected.

APPENDIX A (Cont.)

Round 3

Position and Slant Range, ft	Depth, in.	Phosphate Glass Dosimeters			Quartz-Fibre Dosimeters			Film-Phosphor Dosimeters	Accepted γ-Dose	External γ-Dose	Protection Factor
		Reading	Correction	Corrected Reading	(A)	(B)	(C)				
TA1 (1410)	6	> 9000	N. A.	> 9000	O. S.	O. S.	-	-	> 9000	1.7×10^5	< 20
	12	> 9000	N. A.	> 9000	O. S.	O. S.	-	-	> 9000		< 20
	24	> 9000	N. A.	> 9000	O. S.	O. S.	O. S.	-	> 9000		< 20
	36	1650	40	1610	O. S.	O. S.	O. S.	-	1610		105
	48	115	2	115	80	115	-	> 10	115		1500
	60	-	-	-	-	-	-	7.2	7		2.5×10^4
	72	-	-	-	-	-	-	4.5	5		3.5×10^4
TA2 (1750)	6	> 9000	N. A.	> 9000	O. S.	O. S.	-	-	> 9000	4.5×10^4	< 5
	12	> 9000	N. A.	> 9000	O. S.	O. S.	-	-	> 9000		< 5
	24	5500	630	4870	O. S.	O. S.	O. S.	-	4870		9.3
	36	700	40	660	190	275	300	N. R.	660		69
	48	60	1	60	50	-	-	9.5	-		> 760 < 4800
	60	-	-	-	-	-	-	4.7	5		9100
	72	-	-	-	-	-	-	3.3	3		15000
TA3 (2000)	6	> 9000	N. A.	> 9000	O. S.	O. S.	-	-	> 9000	2.3×10^4	< 2.5
	12	> 9000	N. A.	> 9000	O. S.	O. S.	-	-	> 9000		< 2.5
	24	2680	219	2460	O. S.	O. S.	O. S.	-	2460		9.3
	36	220	11	210	105	160	-	N. R.	210		110
	48	-	-	-	-	-	-	7.5	8		2900
	60	-	-	-	-	-	-	3.9	4		5800
	72	-	-	-	-	-	-	2.0	2		12000
TA4 (2370)	6	> 9000	N. A.	> 9000	O. S.	O. S.	-	-	> 9000	1.2×10^4	< 1.3
	12	7400	559	6840	O. S.	O. S.	O. S.	-	6840		1.8
	24	1150	92	1060	365	485	-	-	1060		11.0
	36	170	6	165	70	120	-	> 10	165		73
	48	60	1	60	-	-	-	8.4	-		> 200 < 1400
	60	-	-	-	-	-	-	5.0	5		2400
	72	-	-	-	-	-	-	3.0	3		4000
TA5 (2695)	6	6300	300*	6000	O. S.	O. S.	-	-	6000	6400	1.1
	12	2450	280	2170	O. S.	O. S.	O. S.	-	2170		2.9
	24	410	51	360	150	245	-	-	360		18
	36	65	2	65	35	60	-	> 10	65		98
	48	20	0	20	-	-	-	3.6	-		> 320 < 1800
	60	-	-	-	-	-	-	1.2	1.5		4300
	72	-	-	-	-	-	-	1.5	1.5		4300
TA6 (3160)	6	2320	100*	2220	O. S.	O. S.	-	-	2220	3600	1.6
	12	910	98	810	360	500+	O. S.	-	810		4.4
	24	150	15	135	65	120	-	> 10	135		26.0
	36	30	0	30	20	-	-	5.9	-		> 120 < 600
	48	10	0	10	-	-	-	2.3	-		> 360 < 1500
	60	-	-	-	-	-	-	1.1	1		3600
	72	-	-	-	-	-	-	0.5	0.5		7200

For Notes, see Appendix A, page 23.

APPENDIX B

Neutron Measurements and Protection Factors: Round 2

Position	Range for Ground Zero, ft	Depth, in.	Thermal Neutron Dose, n/cm^2		Fast Neutron Dose, n/cm^2		Protection Factors	
			Measured	External	Measured	External	Thermal Neutrons	Fast Neutrons
BI1	1348	12	3.36×10^{12}	1.5×10^{13}	1.24×10^{10}	8×10^{11}	4.5	6.5
		24	3.37×10^{11}		1.72×10^{9}		4.5	470
		36	4.39×10^{9}		$< 5 \times 10^{8}$		8.4×10^{3}	1.6×10^{3}
		48	3.19×10^{8}		$< 5 \times 10^{8}$		4.7×10^{4}	1.6×10^{3}
		60	N.R.		N.R.		-	-
		72	N.R.		N.R.		-	-
BI2	1800	12	3.72×10^{11}	4.3×10^{12}	2.23×10^{9}	2.3×10^{11}	12.1	100
		24	2.05×10^{10}		$< 5 \times 10^{8}$		210	
		36	1.02×10^{9}		$< 5 \times 10^{8}$		4200	> 460
		48	2.14×10^{8}		$< 5 \times 10^{8}$		2.0×10^{4}	
		60	$< 10^{7}$		$< 5 \times 10^{8}$		$> 4 \times 10^{5}$	
		72	-		-			
BI3	2100	12	6.74×10^{11}	1.9×10^{12}	4.54×10^{9}	9.5×10^{10}	2.8	21
		24	9.04×10^{10}		1.14×10^{9}		21	84
		36	4.35×10^{9}		$< 5 \times 10^{8}$		440	> 190
		48	1.03×10^{8}		$< 5 \times 10^{8}$		1.8×10^{4}	> 190
		60	N.R.		N.R.		-	-
		72	N.R.		N.R.		-	-
BI4	2400	12	1.55×10^{11}	9.0×10^{11}	1.57×10^{9}	4.4×10^{10}	5.8	28
		24	1.48×10^{10}		$< 5 \times 10^{8}$		61	
		36	7.11×10^{8}		$< 5 \times 10^{8}$		1300	
		48	4.76×10^{7}		$< 5 \times 10^{8}$		1.9×10^{4}	> 88
		60	$< 10^{7}$		$< 5 \times 10^{8}$		$> 9 \times 10^{4}$	
		72	$< 10^{7}$		$< 5 \times 10^{8}$		$> 9 \times 10^{4}$	
BI5	2850	6	3.33×10^{11}	3.0×10^{11}	2.16×10^{9}	1.5×10^{10}	1.0	6.9
		18	1.67×10^{10}		$< 5 \times 10^{8}$		18	
		30	2.40×10^{9}		$< 5 \times 10^{8}$		130	
		42	3.12×10^{7}		$< 5 \times 10^{8}$		9600	> 30
		54	$< 10^{7}$		$< 5 \times 10^{8}$		$> 3 \times 10^{4}$	
		66	$< 10^{7}$		$< 5 \times 10^{8}$		$> 3 \times 10^{4}$	

APPENDIX B (Cont.)

Round 3 (Neutrons)

Position	Slant Range for Burst, ft	Depth, in.	Thermal Neutron Flux, n/cm^2		Fast Neutron Flux, n/cm^2		Protection Factors	
			Measured	External	Measured	External	Thermal Neutrons	Fast Neutrons
TA1	1410	12	4.44×10^{13}	8.2×10^{13}	3.53×10^{11}	2.2×10^{12}	1.8	6.2
		24	5.21×10^{12}		4.03×10^{10}		16	55
		36	4.11×10^{11}		4.76×10^{9}		200	460
		48	1.77×10^{10}		$< 5 \times 10^{8}$		4600	> 4400
		72	4.35×10^{8}		$< 5 \times 10^{8}$		1.9×10^{5}	-
TA2	1750	12	3.03×10^{13}	3.0×10^{13}	1.74×10^{11}	1.1×10^{12}	1.0	6.3
		24	6.32×10^{12}		2.10×10^{10}		4.7	52
		36	4.04×10^{11}		2.23×10^{9}		74	490
		48	1.14×10^{10}		$< 5 \times 10^{8}$		2600	> 2200
		72	1.57×10^{8}		$< 5 \times 10^{8}$		1.9×10^{5}	-
TA3	2000	12	1.36×10^{13}	1.6×10^{13}	7.32×10^{10}	6.0×10^{11}	1.2	8.2
		24	2.19×10^{12}		6.96×10^{9}		7.3	86
		36	1.08×10^{11}		$< 5 \times 10^{8}$		150	> 1200
		48	6.53×10^{9}		$< 5 \times 10^{8}$		2500	-
		72	2.71×10^{7}		$< 5 \times 10^{8}$		5.9×10^{5}	-
TA4	2370	12	5.59×10^{12}	6.0×10^{12}	3.37×10^{10}	2.7×10^{11}	1.1	8.0
		24	9.20×10^{11}		3.66×10^{9}		6.5	74
		36	6.23×10^{10}		$< 5 \times 10^{8}$		96	> 540
		48	1.12×10^{10}		$< 5 \times 10^{8}$		540	-
		72	1.63×10^{8}		$< 5 \times 10^{8}$		3.7×10^{4}	-
TA5	2695	12	2.82×10^{12}	2.9×10^{12}	1.16×10^{10}	1.4×10^{11}	1.0	12.0
		24	5.13×10^{11}		1.39×10^{9}		5.6	100
		36	1.54×10^{10}		$< 5 \times 10^{8}$		190	> 280
		48	7.89×10^{8}		$< 5 \times 10^{8}$		3700	-
		72	$< 10^{7}$		$< 5 \times 10^{8}$		$> 2.9 \times 10^{5}$	-
TA6	3160	12	9.77×10^{11}	1.0×10^{12}	4.79×10^{9}	5.1×10^{10}	1.0	11
		24	1.49×10^{11}		$< 5 \times 10^{8}$		6.7	> 100
		36	4.35×10^{9}		$< 5 \times 10^{8}$		230	-
		48	1.15×10^{8}		$< 5 \times 10^{8}$		8700	-
		72	1.56×10^{7}		$< 5 \times 10^{8}$		6.4×10^{4}	-

SECRET ATOMIC
U.K. EYES ONLY

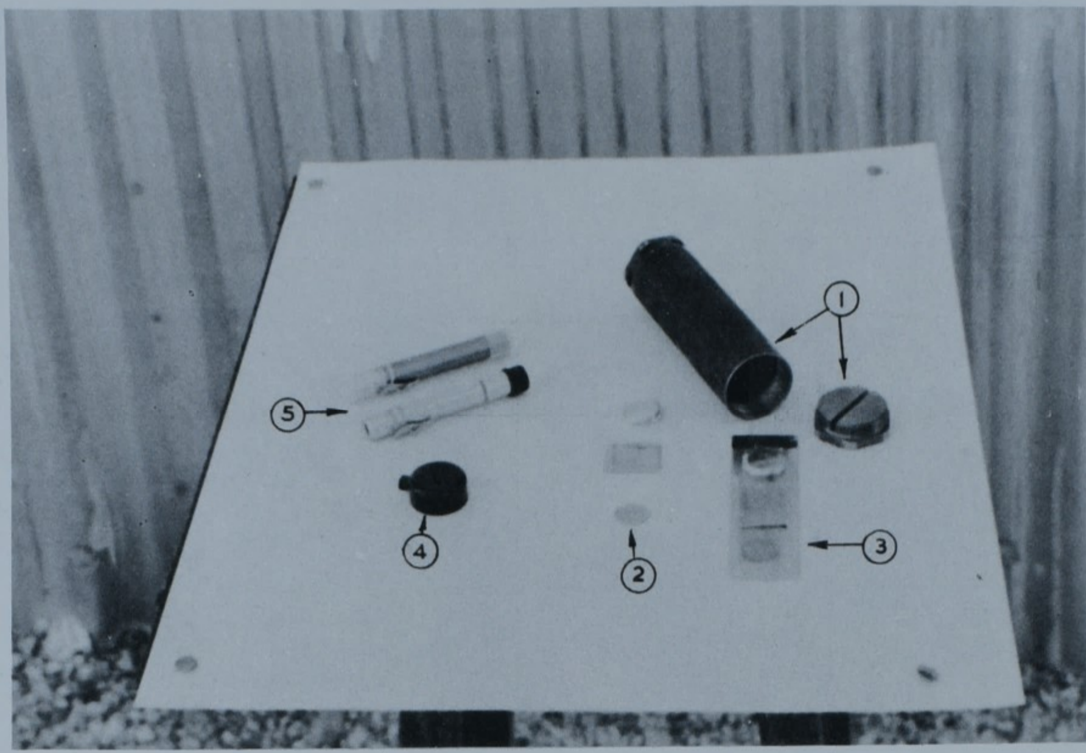

FIGURE I. THE DOSIMETERS WHICH WERE PLACED AT EACH DEPTH.

KEY

1. THE NEUTRON DOSIMETER TUBE AND CAP.
2. THE THREE ELEMENTS (FROM TOP TO BOTTOM)

   SULPHUR, PROTECTED BY TWO ALUMINIUM PLANCHETTES.

   GOLD, CLAD IN CADMIUM.

   GOLD.
3. THE THREE ELEMENTS, MOUNTED ON THE ALUMINIUM SLIDE PRIOR TO INSERTION INTO THE STEEL TUBE.
4. A SERVICE PHOSPHATE-GLASS DOSIMETER.
5. TWO TYPICAL QF DOSIMETERS.

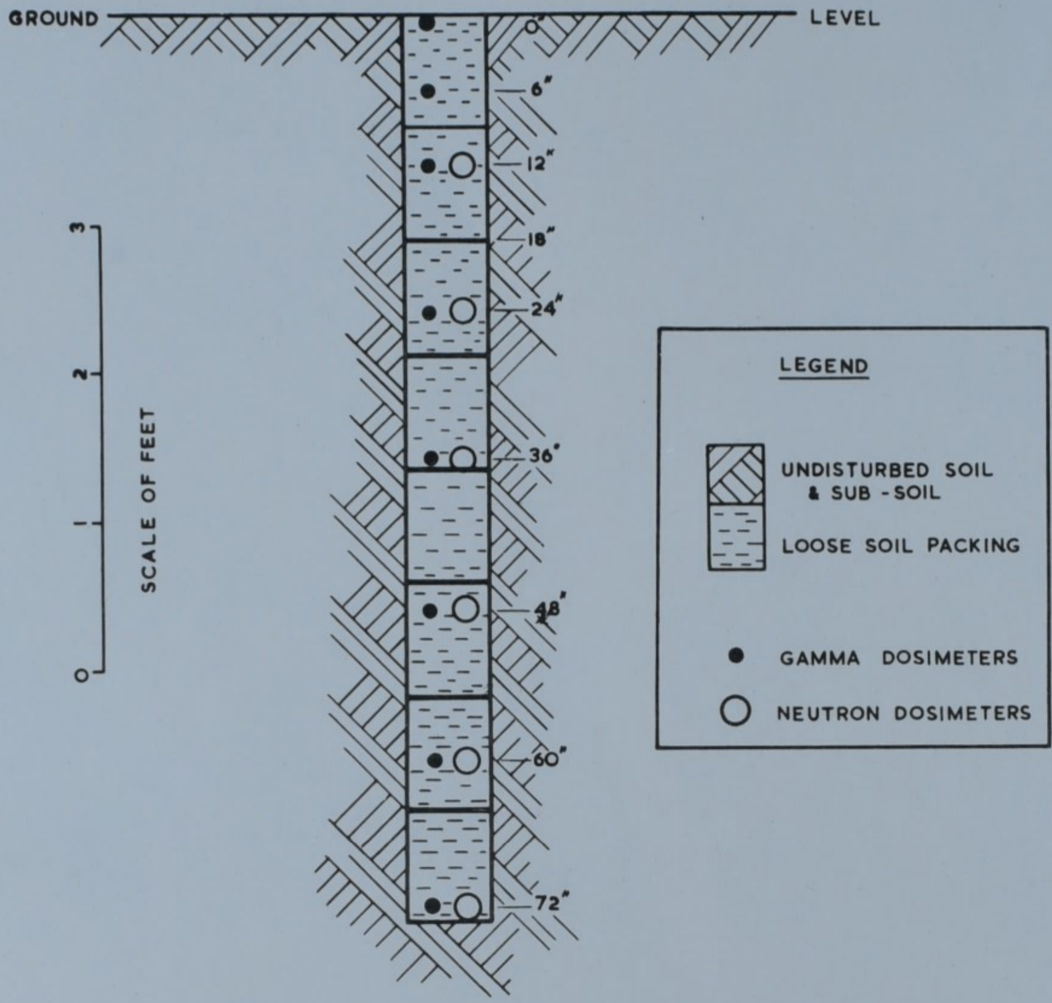

FIGURE 2 SECTION THROUGH SUNKEN PIPE SHOWING CANS CONTAINING DOSIMETERS

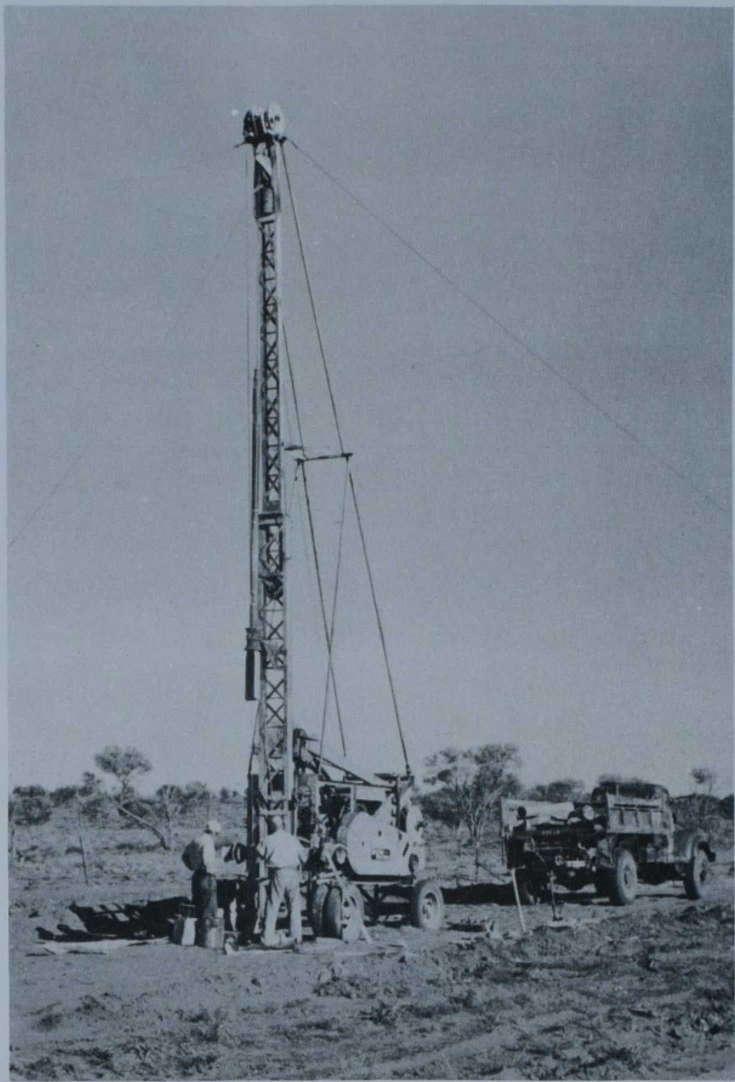

FIGURE 3. THE WELL-BORING MACHINE IN OPERATION

FIGURE 4. THE CONTENTS OF THE HOLE, AS THROWN OUT BY THE WELL-BORER. THE SPOIL WAS THROWN OUT AS A SLURRY OF APPROXIMATELY THE SAME CONSISTENCY AS FRESHLY-MIXED CONCRETE.

FIGURE 5. A CAN, FILLED WITH ITS DOSIMETERS AND SOIL, BEING LOWERED INTO A HOLE BY A "SHEPHERD'S CROOK".

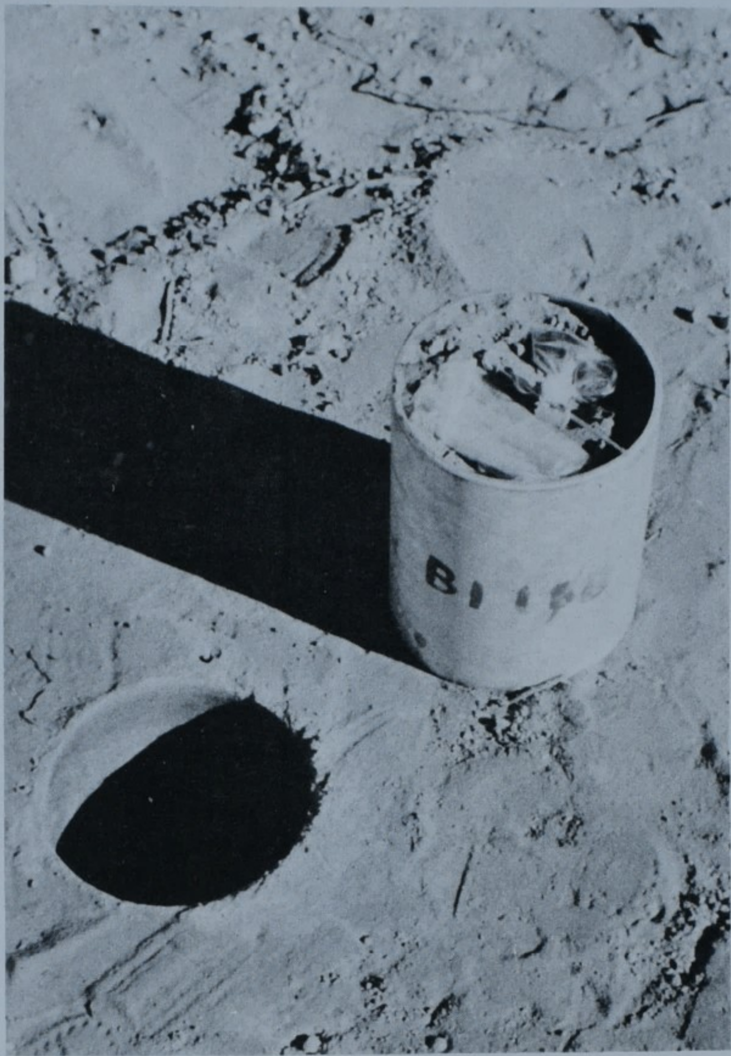

FIGURE 6. A FILLED CAN, IN THIS CASE ONE WITH THE DOSIMETERS AT THE TOP, READY TO BE LOWERED INTO A HOLE.

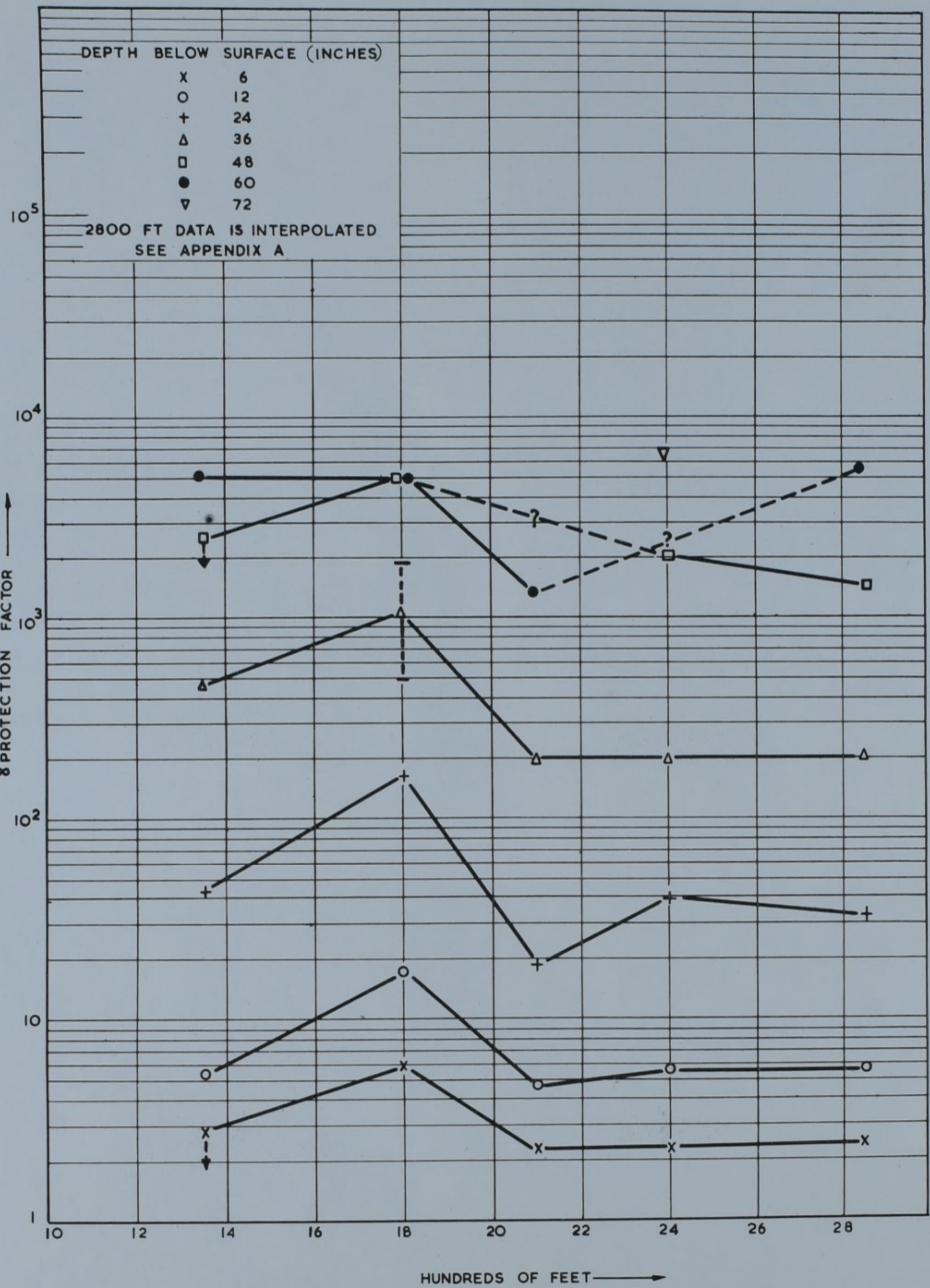

FIGURE 7a. ROUND 2 γ RADIATION PROTECTION FACTORS

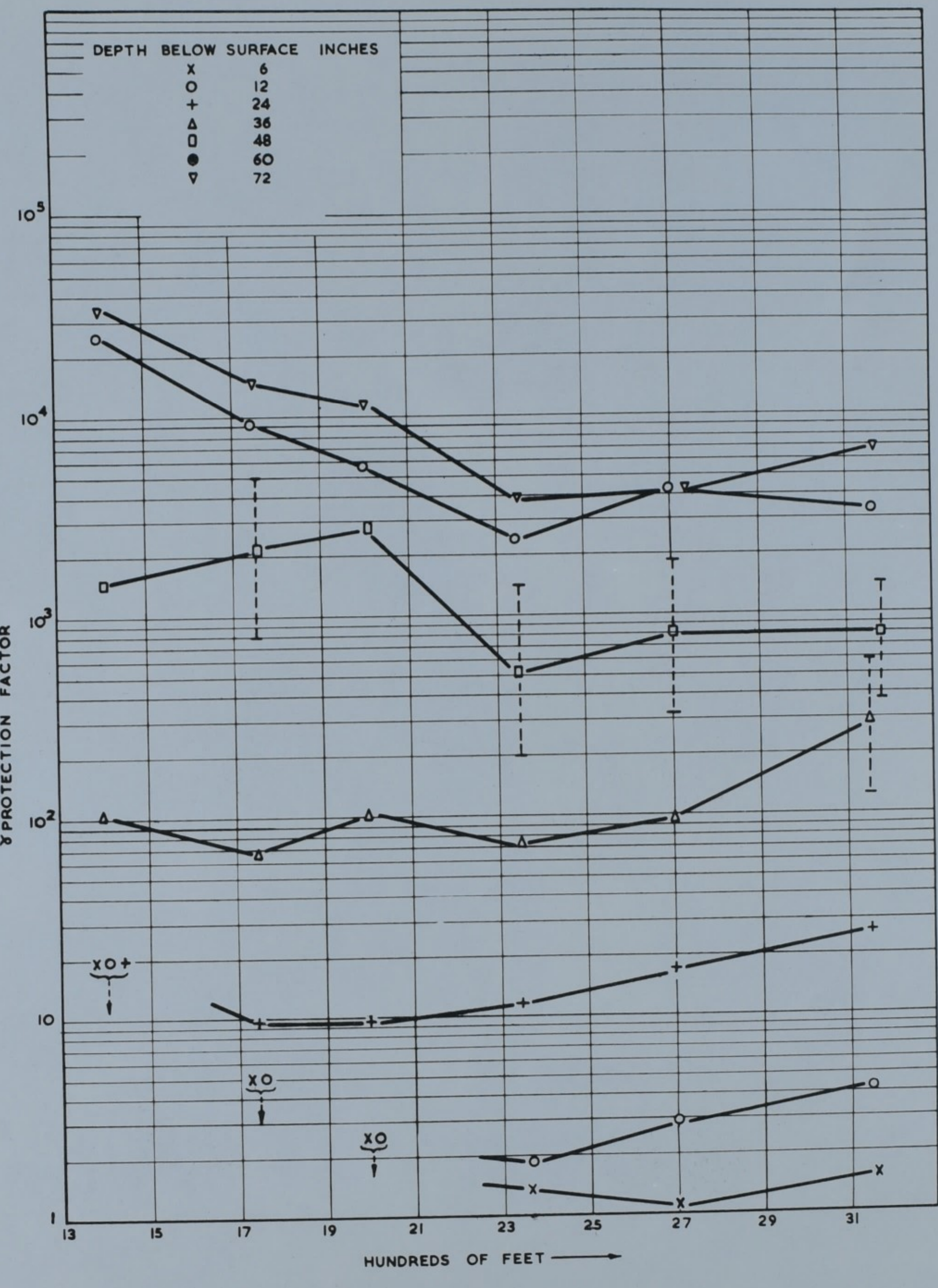

FIGURE 7b. ROUND 3 γ RADIATION PROTECTION FACTORS

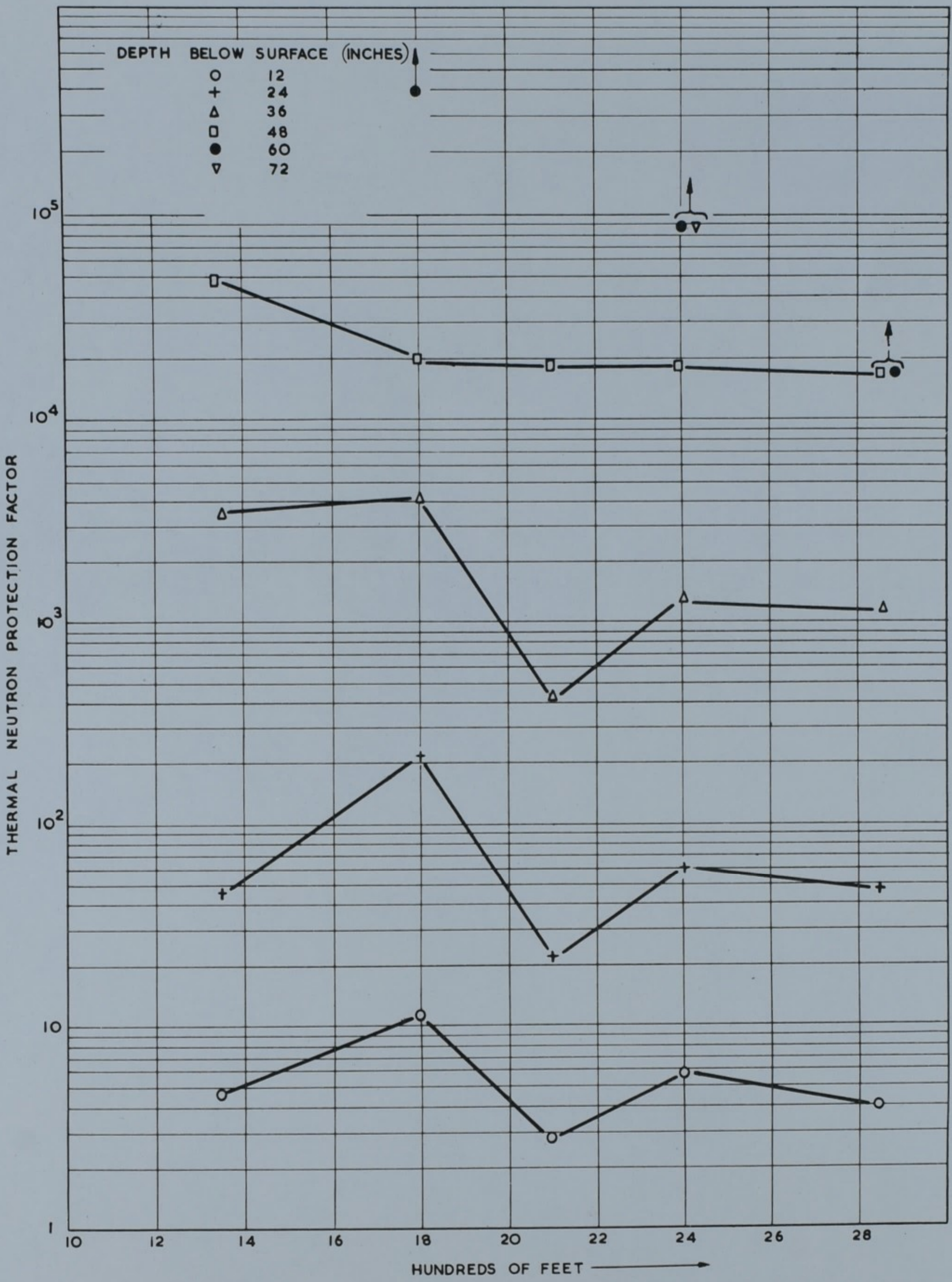

FIGURE 8a ROUND 2 THERMAL NEUTRON PROTECTION FACTORS

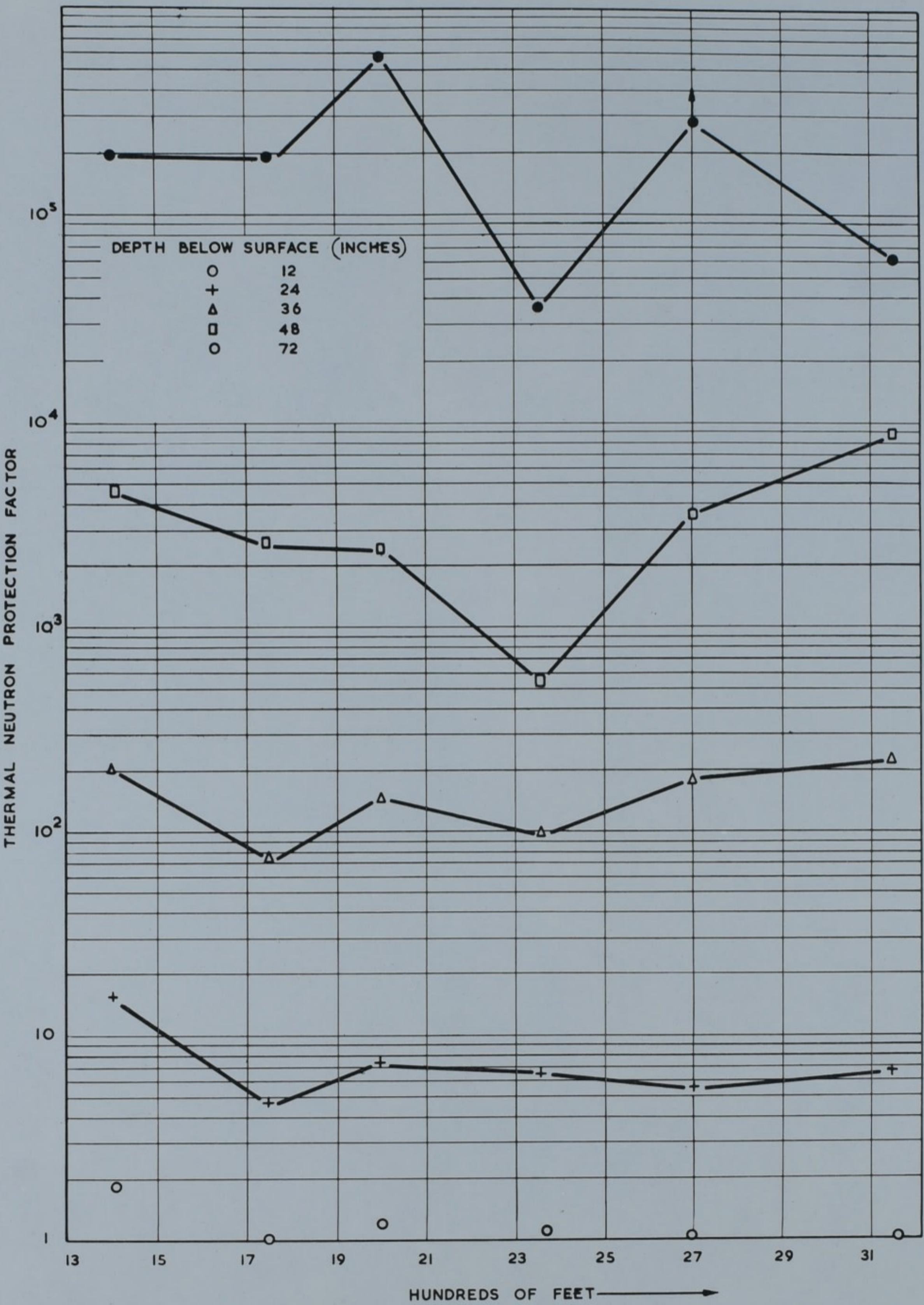

FIGURE 8b. ROUND 3 THERMAL NEUTRON PROTECTION FACTORS

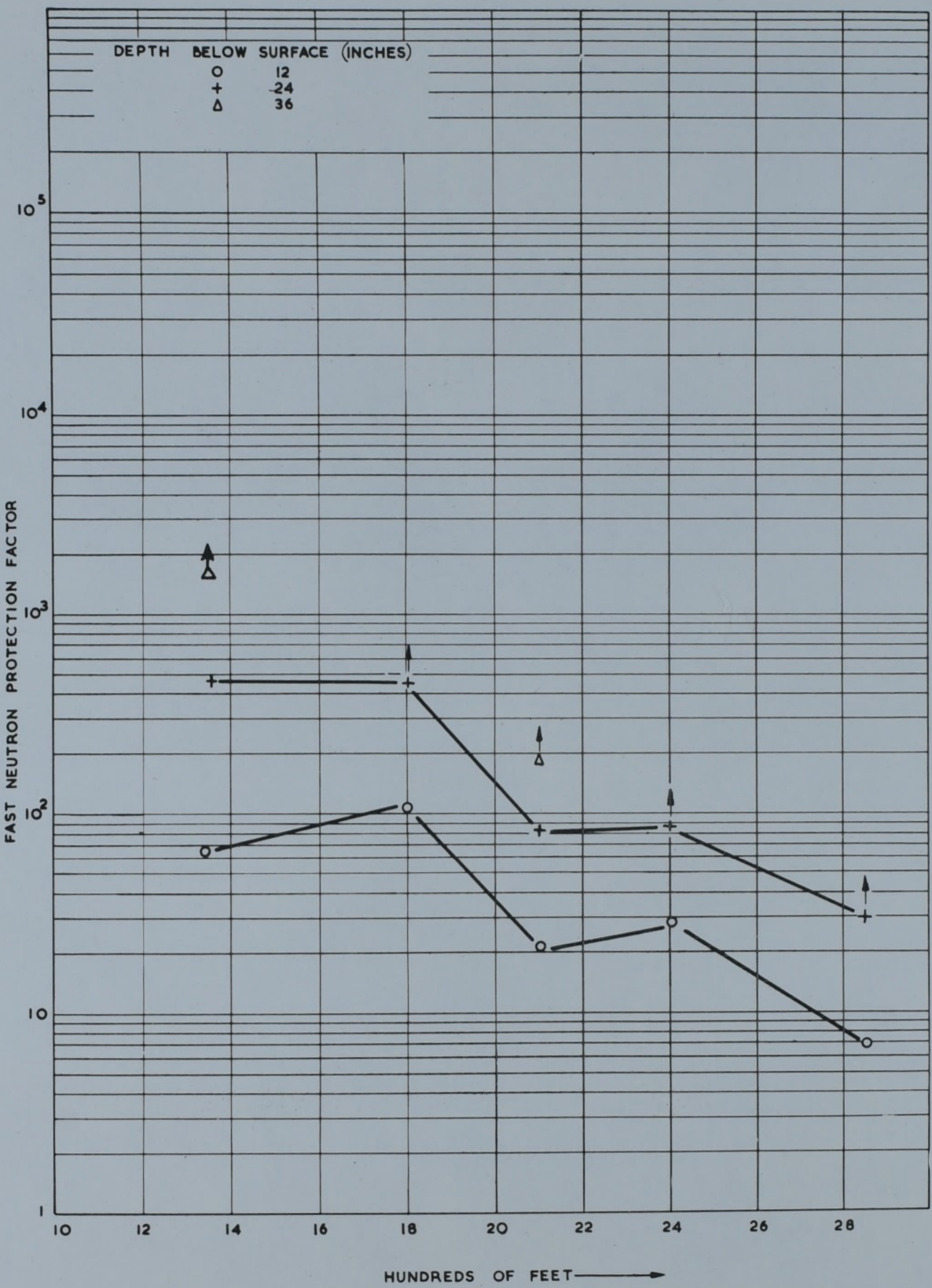

FIGURE 9a. ROUND 2 FAST NEUTRON PROTECTION FACTORS

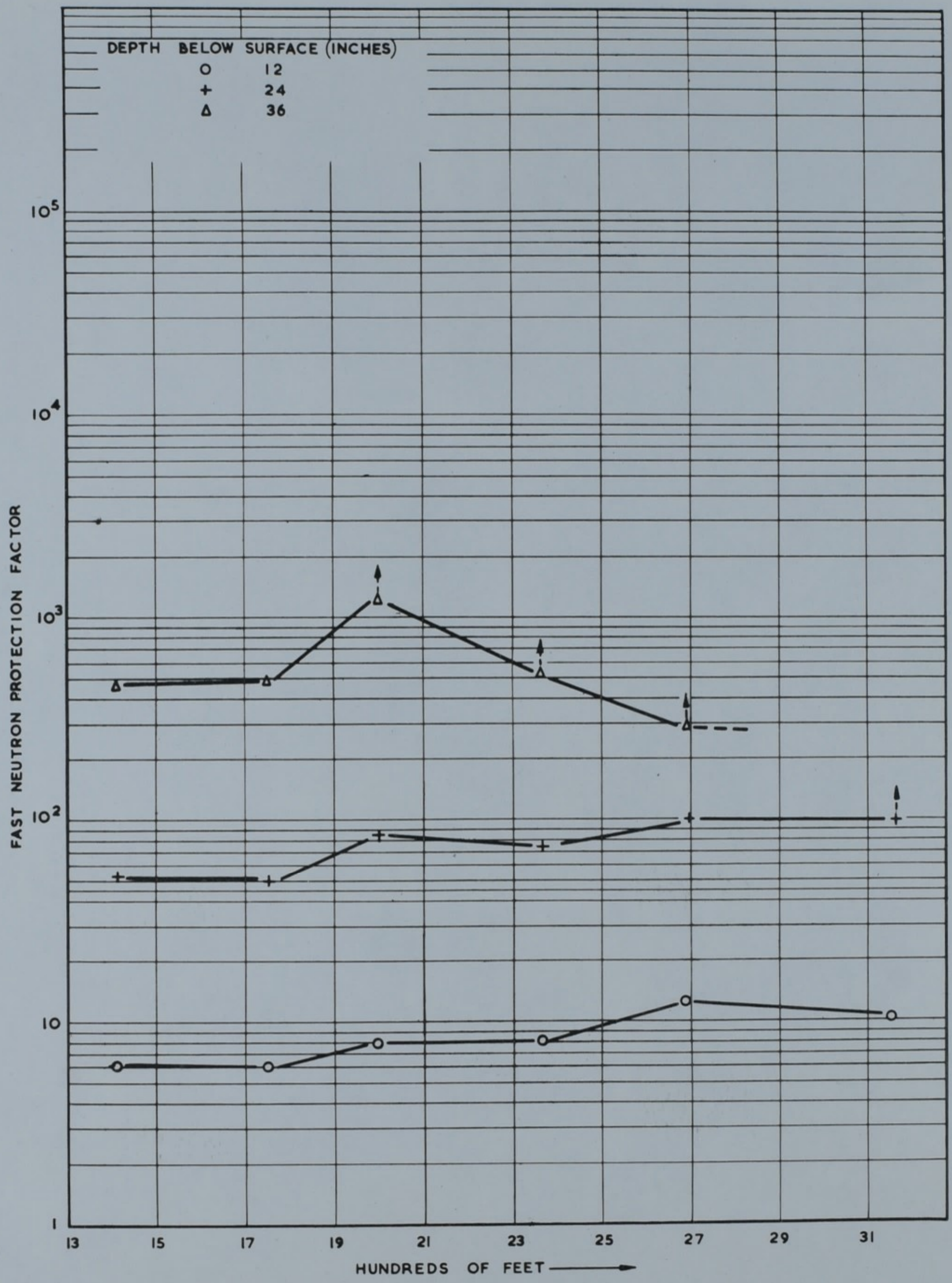

FIGURE 9b ROUND 3 FAST NEUTRON PROTECTION FACTORS

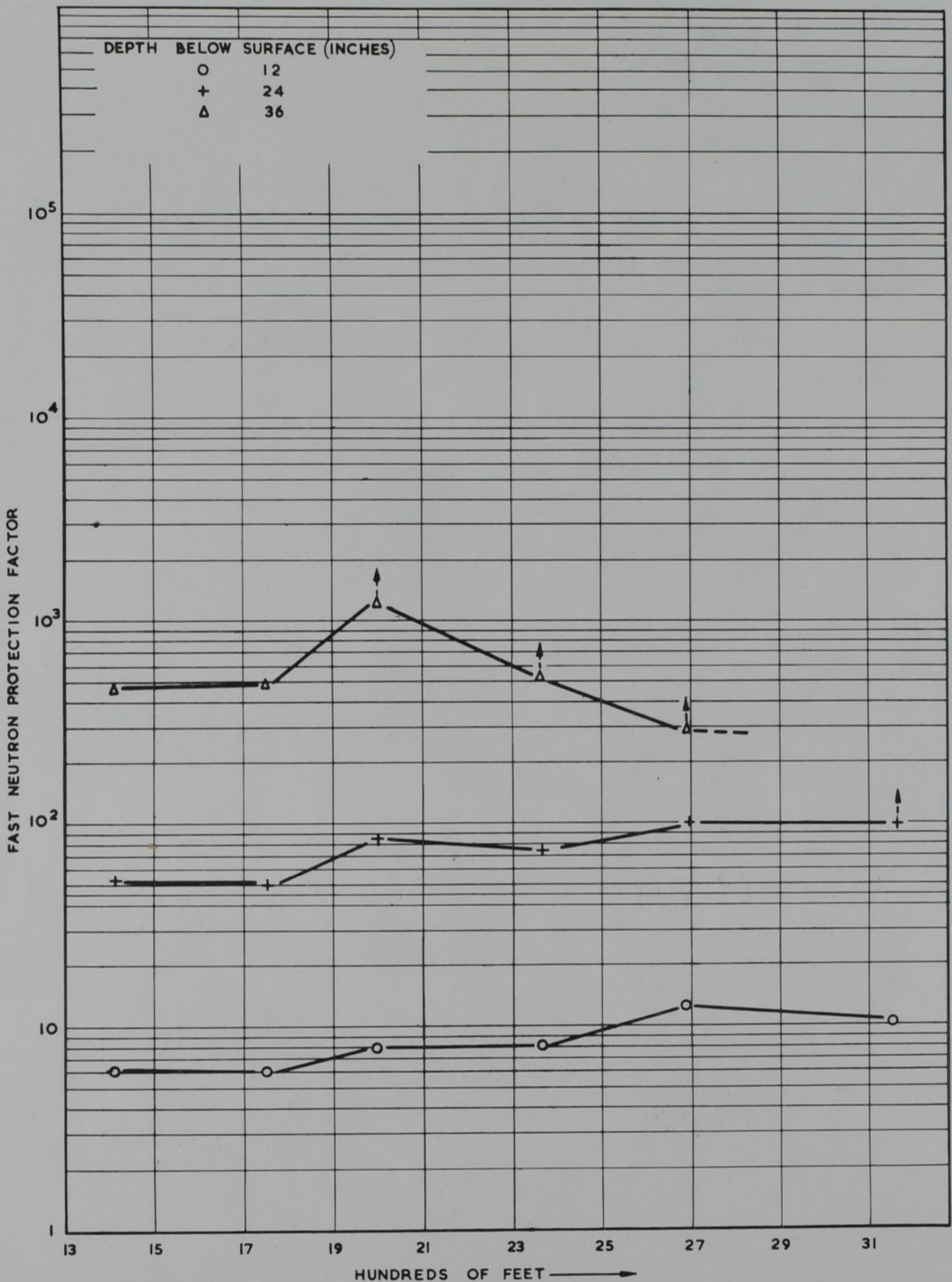

FIGURE 9b ROUND 3 FAST NEUTRON PROTECTION FACTORS

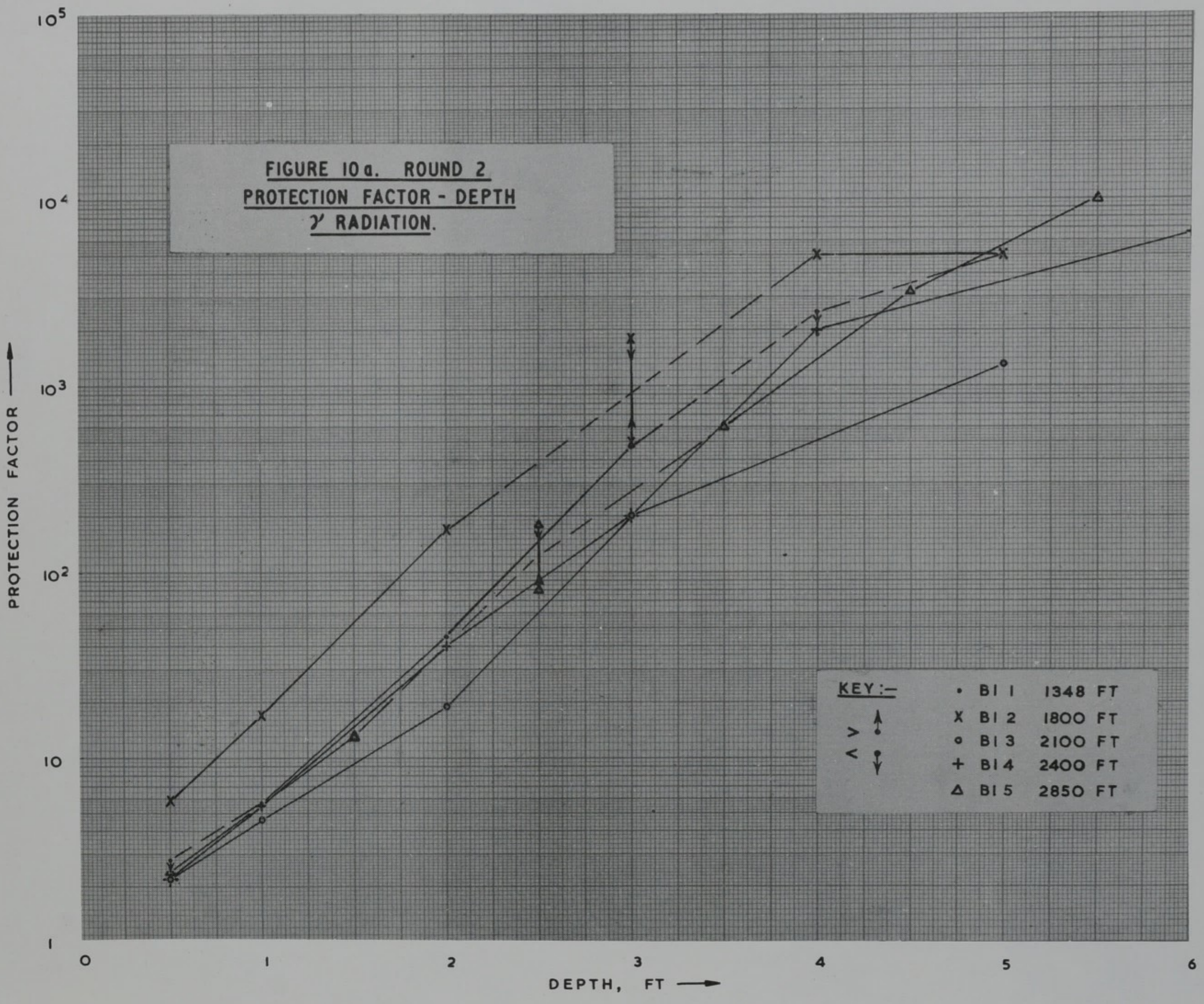
FIGURE 10a. ROUND 2
PROTECTION FACTOR - DEPTH
γ RADIATION.
PROTECTION FACTOR
1
10
10²
10³
10⁴
10⁵
DEPTH, FT
0
1
2
3
4
5
6
KEY:-
• BI 1 1348 FT
X BI 2 1800 FT
o BI 3 2100 FT
+ BI 4 2400 FT
Δ BI 5 2850 FT
>

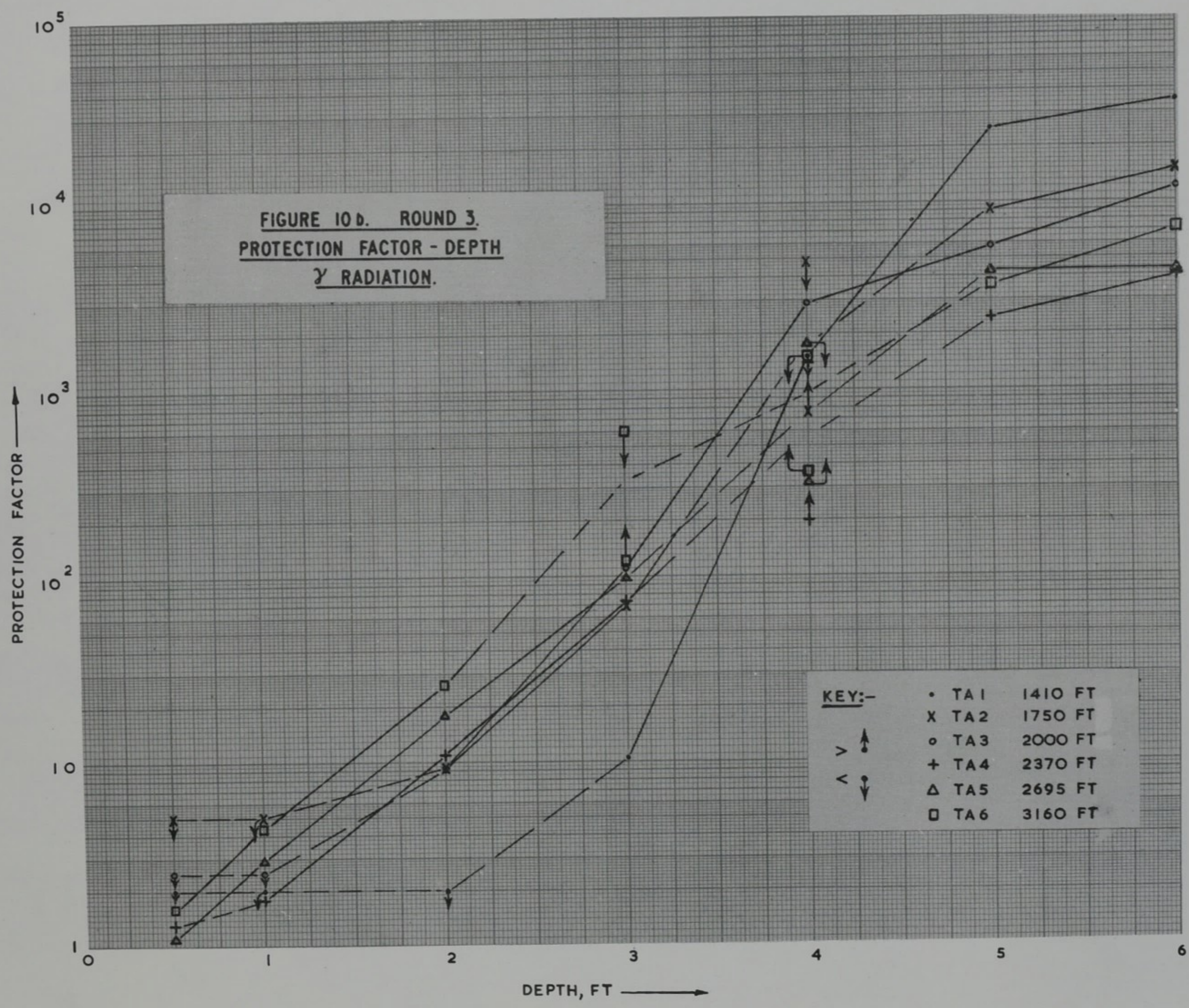

FIGURE 10b. ROUND 3.
PROTECTION FACTOR - DEPTH
γ RADIATION.

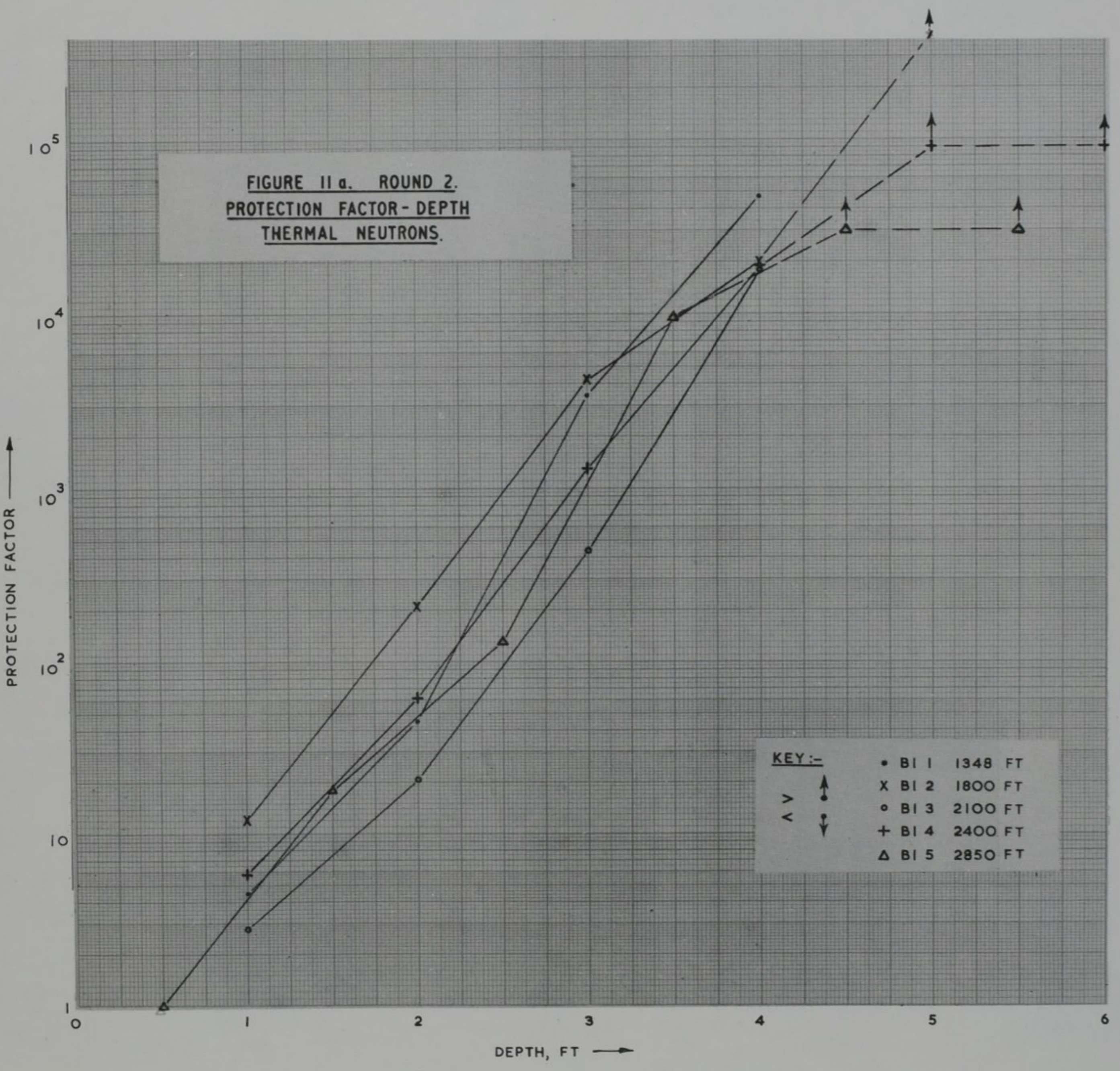
FIGURE 11 a. ROUND 2.
PROTECTION FACTOR - DEPTH
THERMAL NEUTRONS.
PROTECTION FACTOR
DEPTH, FT
1
10
10^2
10^3
10^4
10^5
0
1
2
3
4
5
6
KEY :-
• BI 1 1348 FT
X BI 2 1800 FT
o BI 3 2100 FT
+ BI 4 2400 FT
Δ BI 5 2850 FT
>
<

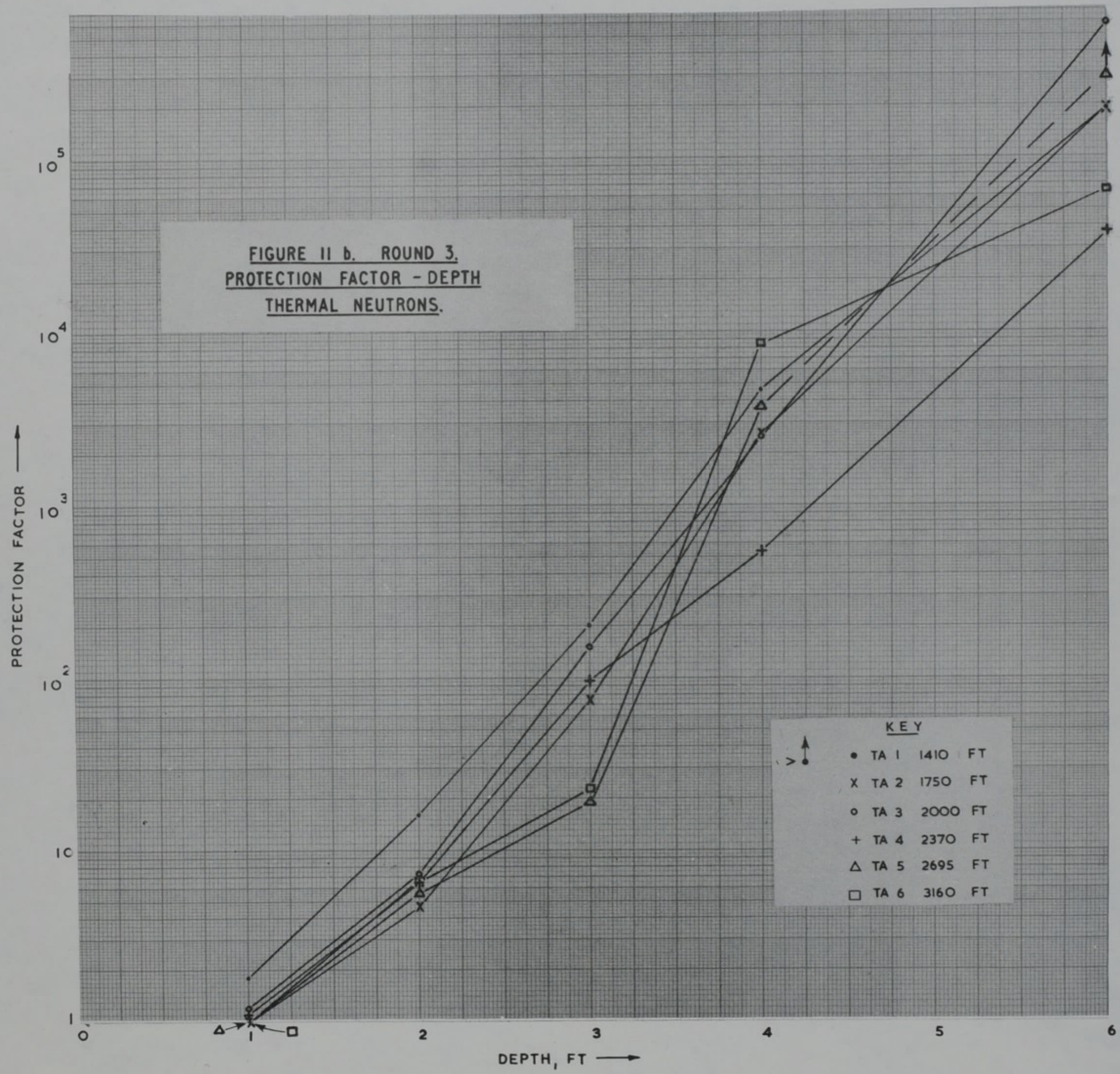

FIGURE II b. ROUND 3.
PROTECTION FACTOR - DEPTH
THERMAL NEUTRONS.

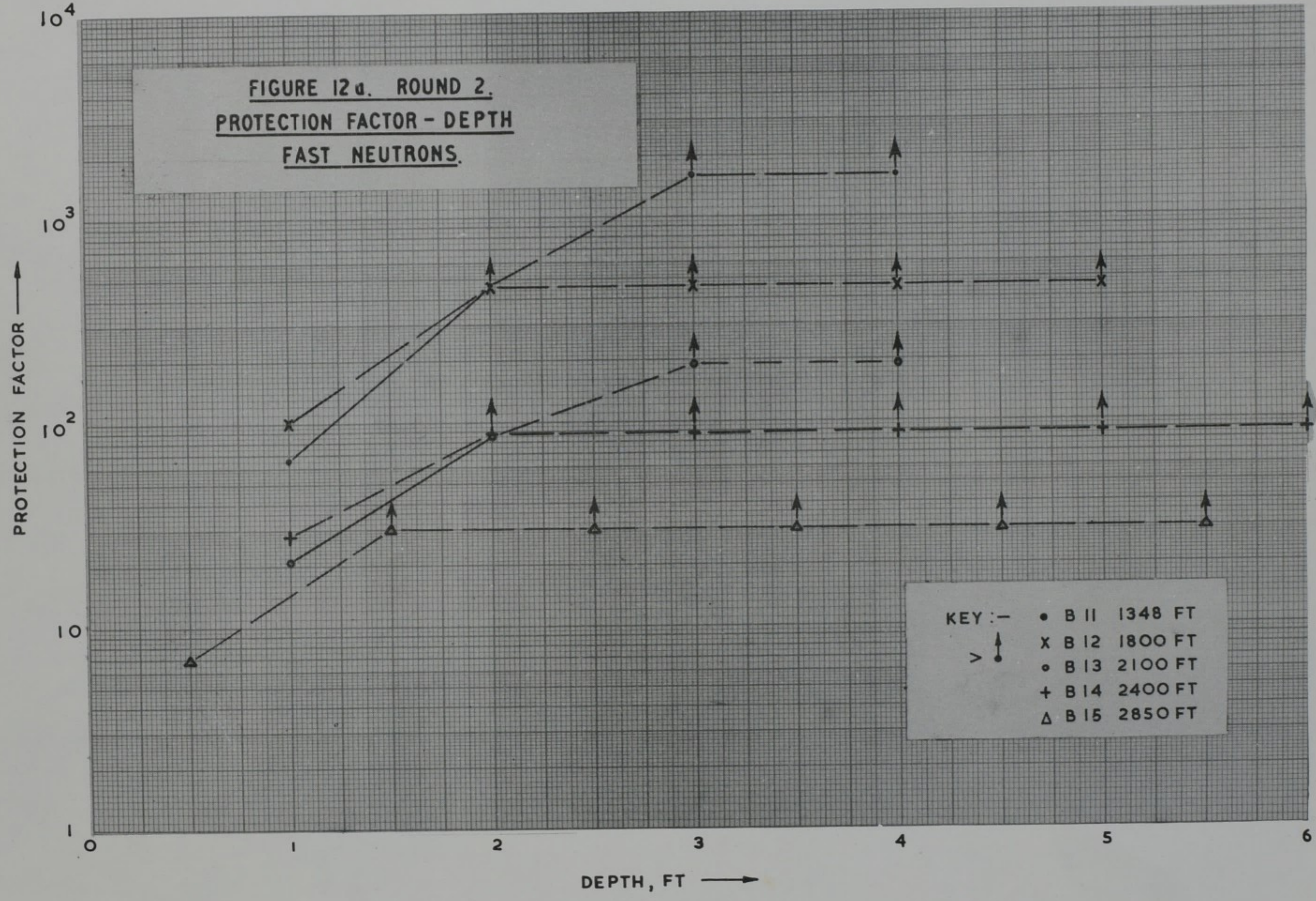
FIGURE 12a. ROUND 2.
PROTECTION FACTOR - DEPTH
FAST NEUTRONS.
PROTECTION FACTOR
1
10
10^2
10^3
10^4
DEPTH, FT
0
1
2
3
4
5
6
KEY :-
>
• B 11 1348 FT
X B 12 1800 FT
∘ B 13 2100 FT
+ B 14 2400 FT
Δ B 15 2850 FT

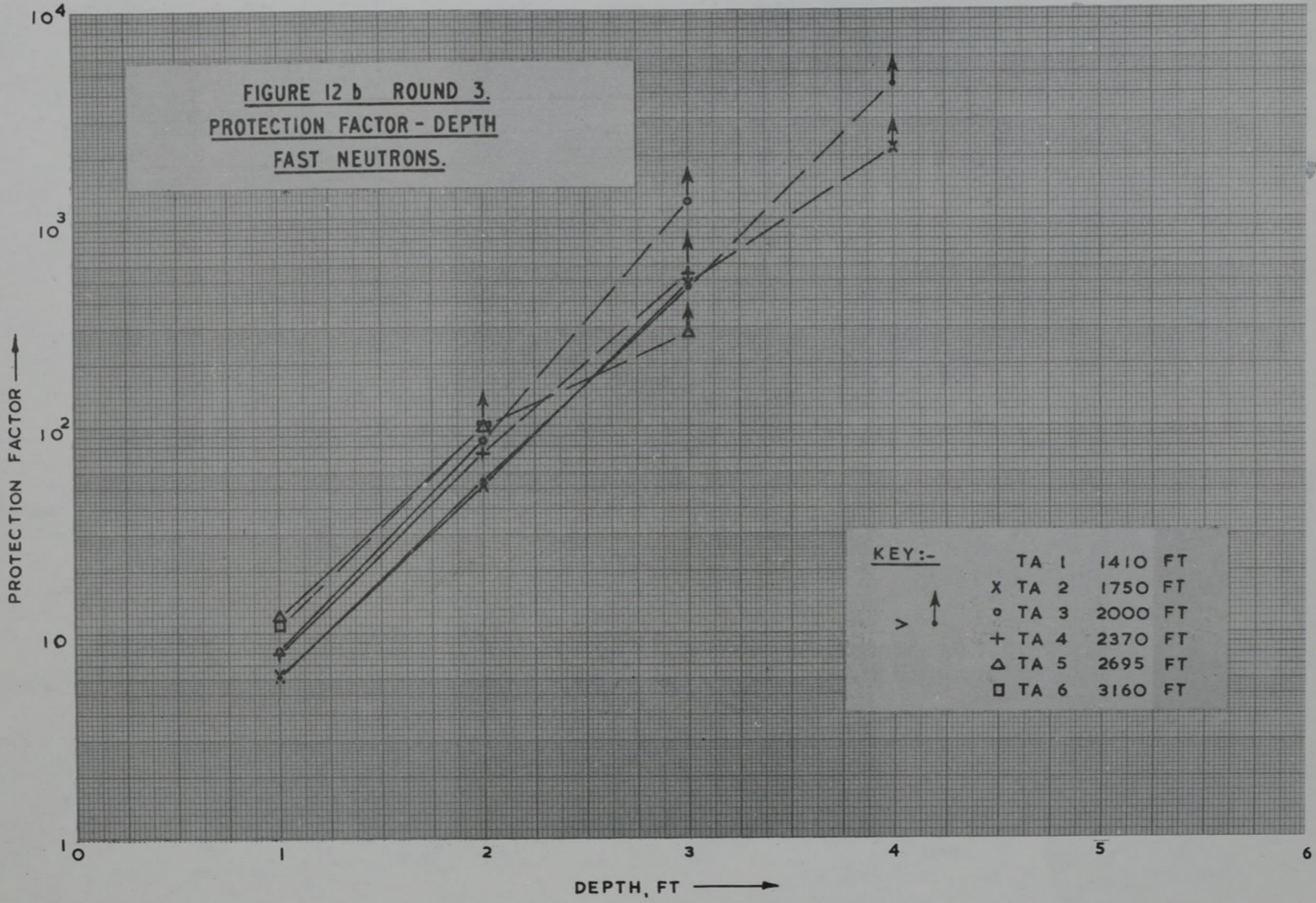

FIGURE 12 b ROUND 3.
PROTECTION FACTOR - DEPTH
FAST NEUTRONS.